BIOMETRIC SIGNATURE AUTHENTICATION WITH LOW-COST EMBEDDED STYLUS

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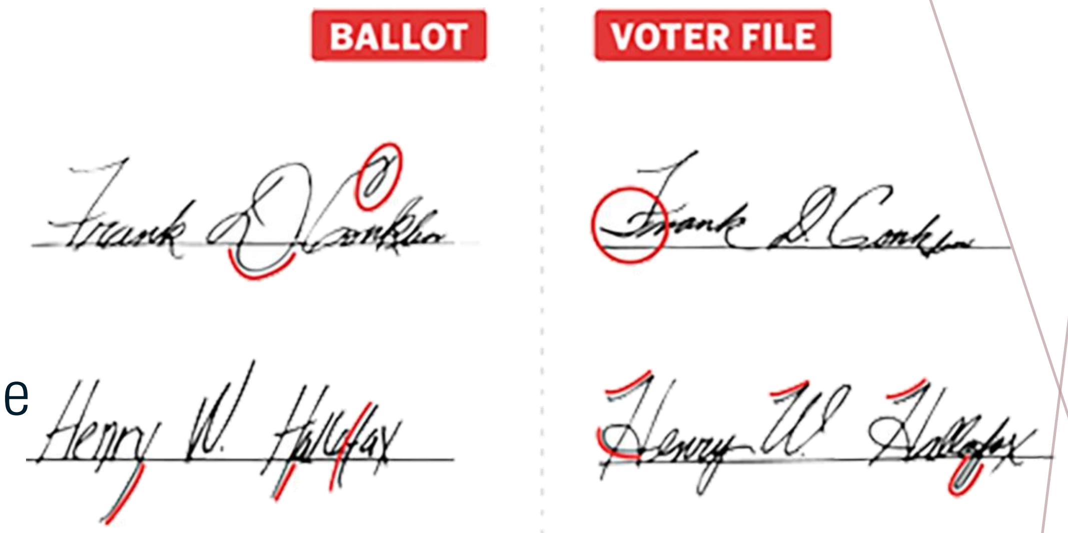
MOTIVATION

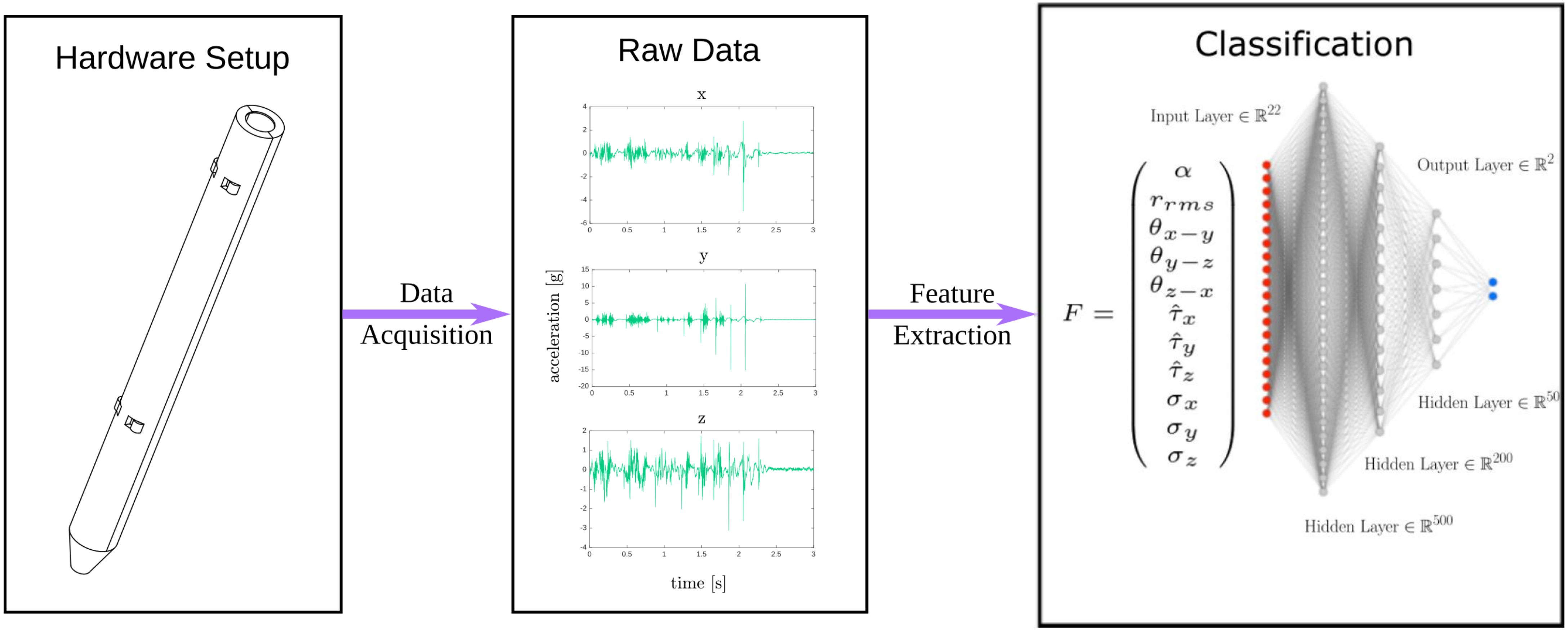


- Current authentication methods
  - Passwords, MFA
- Signatures have been used as form of authentication
  - Used in ballots, checks, legally binding papers
- Current signature verification methods are not reliable
  - Extremely manual and expensive undertaking
  - Observed utility of their expertise over novices are not entirely confirmed
- Handwriting and signatures is unique to each individual person
- Non-invasive, user-friendly and can be readily integrated into current system

RESEARCH GOALS

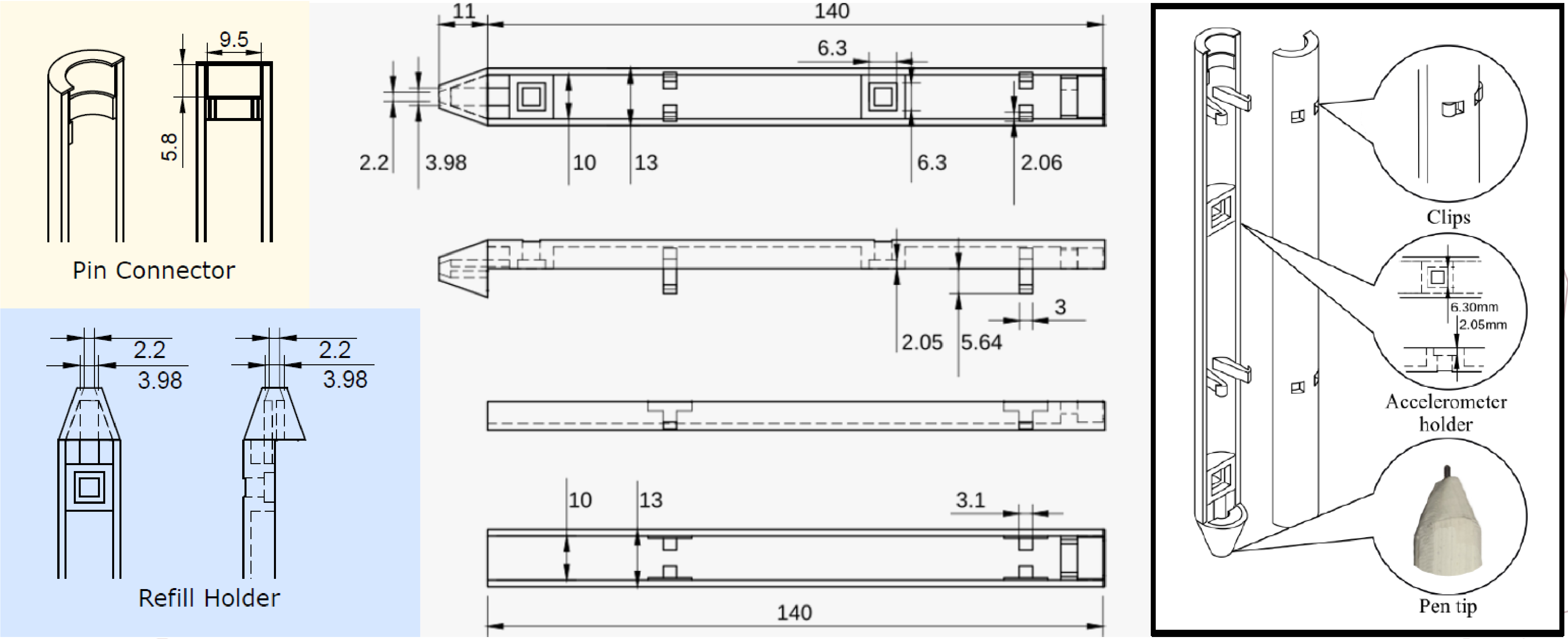
- Design and develop a low-cost pen that authenticates users via signature
- Propose a novel approach to use signature as biometric authentication
  - Observe how the signature was written rather than just the outcome
  - This iteration of the device is based on inertial measurements collected by two accelerometers
- Extract features based on collected data
- Train a model using the features that can authenticate a signature

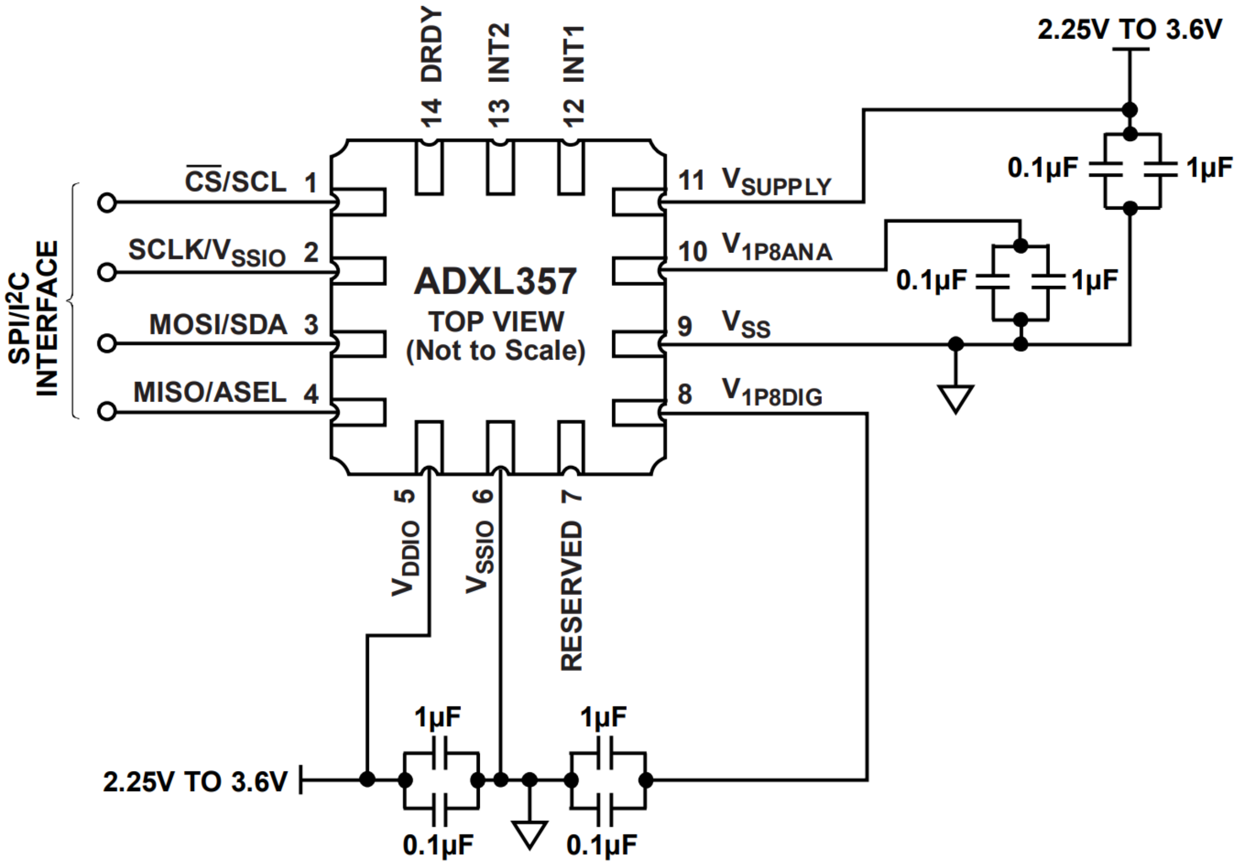
WORKFLOW



Hardware Setup
Data Acquisition
Raw Data
x
y
z
acceleration [g]
time [s]
Feature Extraction
Classification
Input Layer $\in \mathbb{R}^{22}$
Output Layer $\in \mathbb{R}^{2}$
Hidden Layer $\in \mathbb{R}^{50}$
Hidden Layer $\in \mathbb{R}^{200}$
Hidden Layer $\in \mathbb{R}^{500}$
$F = \begin{pmatrix} \alpha \\ r_{rms} \\ \theta_{x-y} \\ \theta_{y-z} \\ \theta_{z-x} \\ \hat{\tau}_x \\ \hat{\tau}_y \\ \hat{\tau}_z \\ \sigma_x \\ \sigma_y \\ \sigma_z \end{pmatrix}$

STYLUS DESIGN



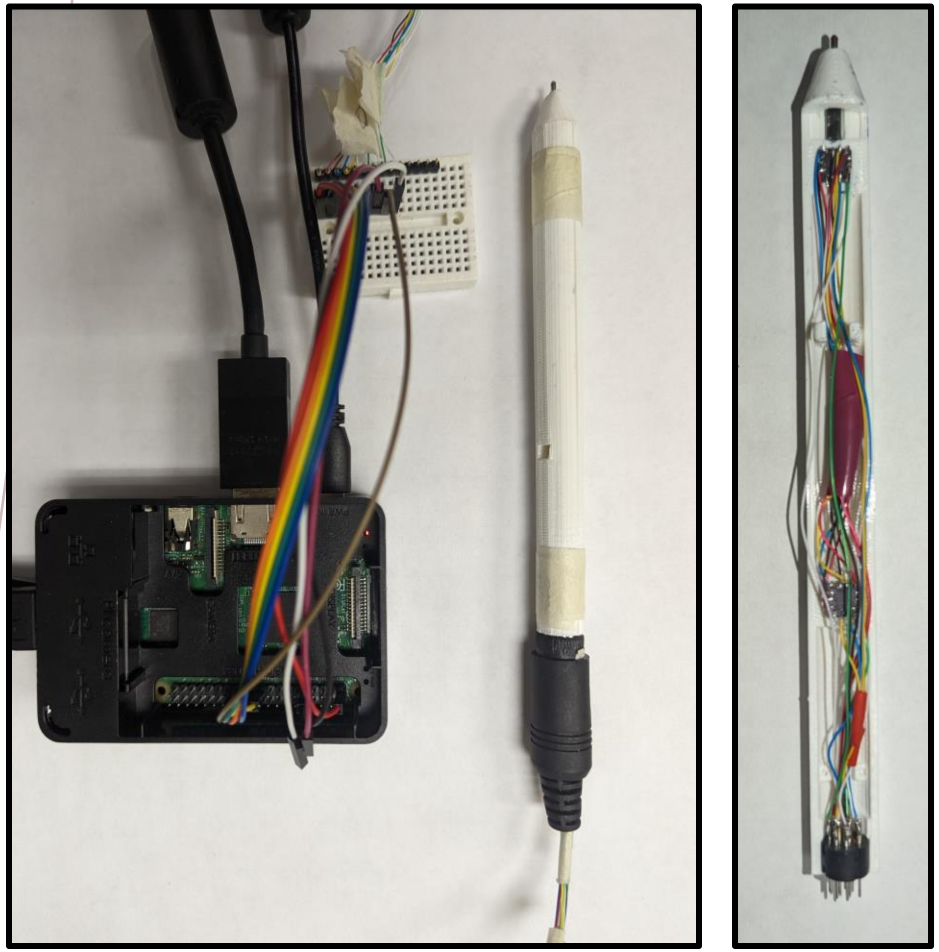


Circuit layout for one ADXL357

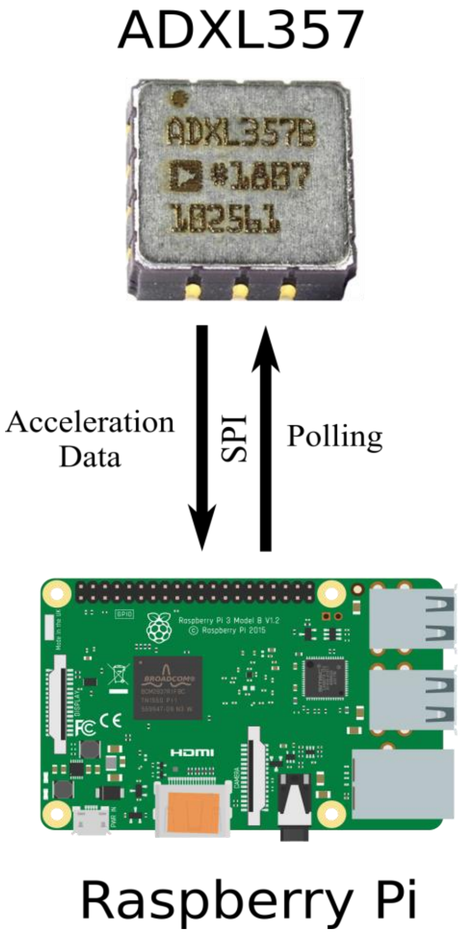
ACCELEROMETER

ADXL357

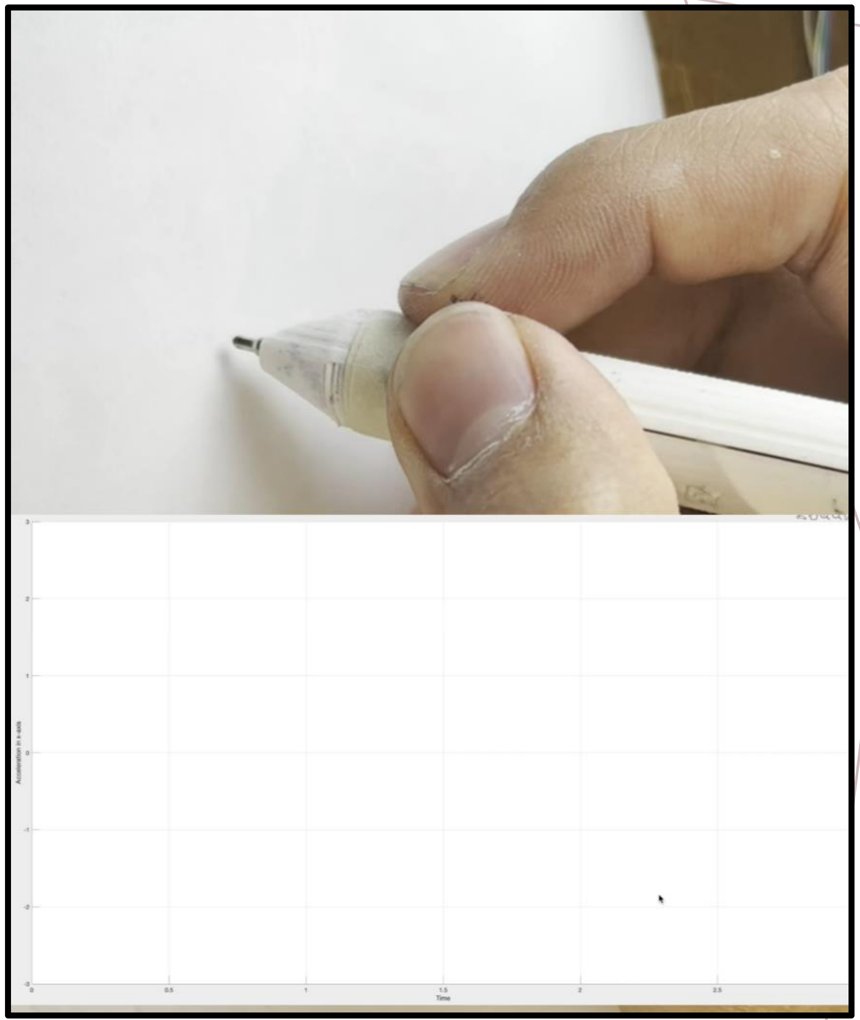
- 3 Axes measurement
- Bandwidth: 2 kHz
- Range: 20g
- Sensitivity: 7.23 * 10^{-4} g
- Serial Peripheral Interface (3.4 MHz)



Physical realization of the pen



Data Acquisition Process



Collection of acceleration data from signature

DATA COLLECTION

Two separate users' signatures served as authentication targets: **Subject 0** and **Subject 1**

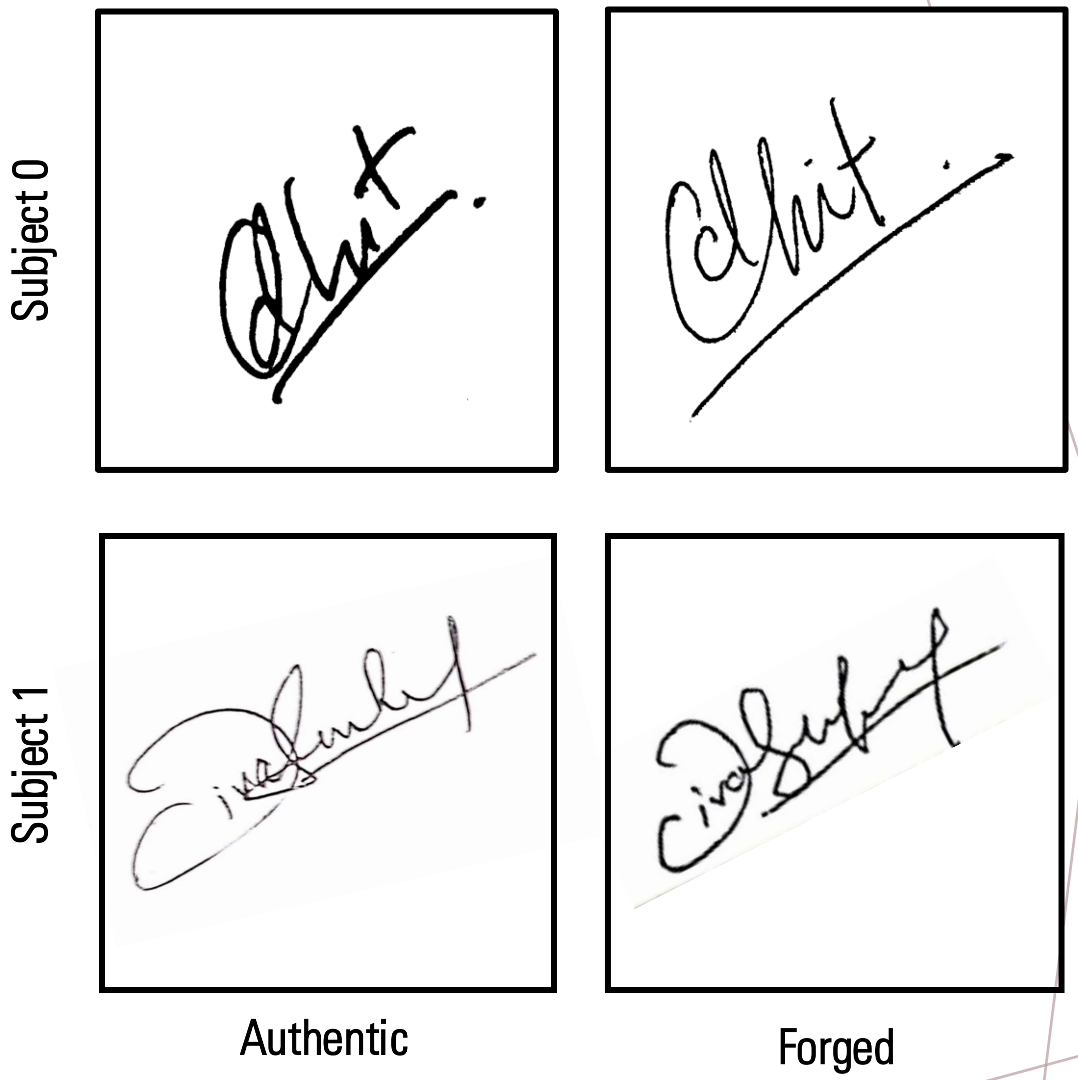
Two signature labels were collected: **Authentic** and **Forged**

Authentic Signature [2 Subjects]

- 212 signatures

Forged Signature [8 Subjects]:

- 30 forged signatures
- 15 random words/scribbles

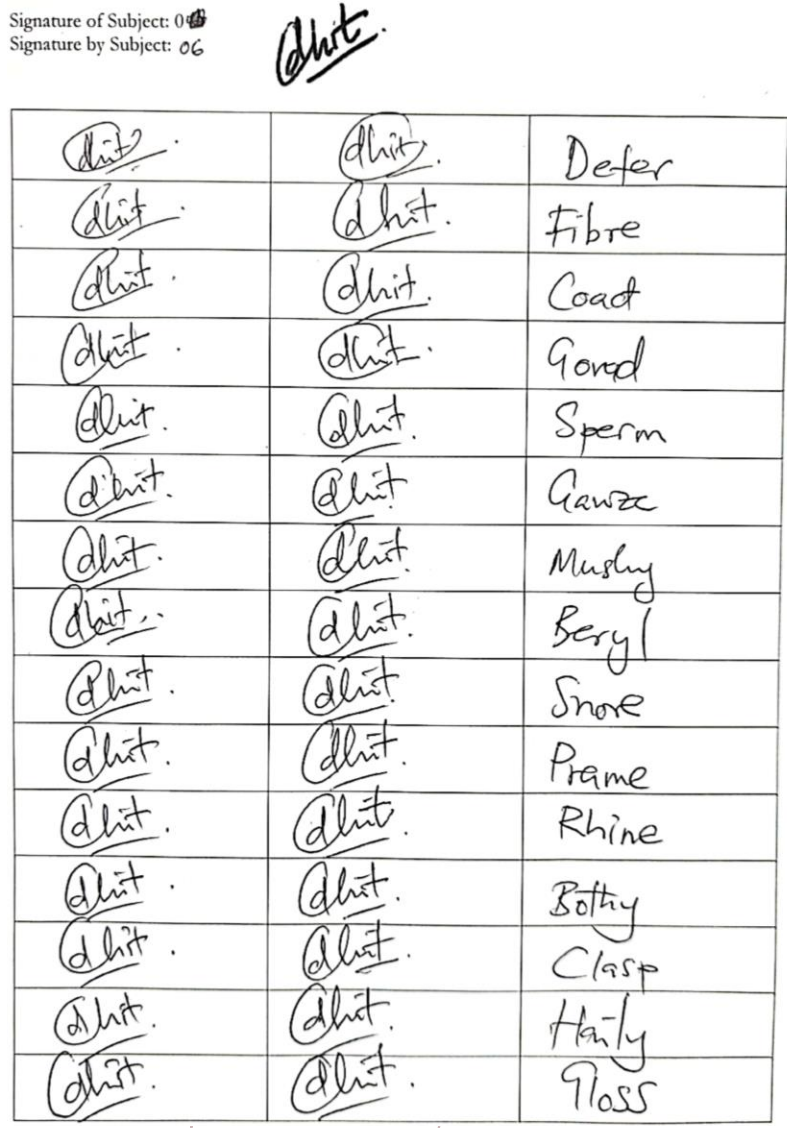


DATA COLLECTION

The subjects were all right-handed and between the ages of 18 and 23 years old

A brief introduction to the forgery task included:

- an introduction to the embedded device
- a description of the time duration:
  - under 3 seconds for Subject 0
  - under 5 seconds for Subject 1
- for each signature class, a copy (to scale) of the authentic signature graphical output
- time for the forger to practice with the pen to forge the target signature (20 minutes or whenever satisfied)



DATA COLLECTION

For both Subject 0 and Subject 1 signatures, a database is collected that includes acceleration time series for:

1. 212 handwritten positive (authentic) signatures;
2. 343 handwritten negative (forged) signatures, consisting of:

    - 238 forged replicas of authentic signature;

    - 105 random words/scribbles.

Each type of signature thus includes a total of 555 collected samples as a dataset

ORIENTATION NORMALIZATION

$$v = -\frac{\hat{a}_{\perp g}}{\|\hat{a}_{\perp g}\|}$$

$$G = \begin{bmatrix} \hat{a} \cdot g & -\|\hat{a} \times g\| & 0 \\ \|\hat{a} \times g\| & \hat{a} \cdot g & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$F = \begin{bmatrix} \hat{a} & v & g \times \hat{a} \end{bmatrix}$$

$$U = F \cdot G \cdot F^{-1}$$

FEATURES

$$\alpha = \arccos\left(\hat{\mathbf{a}} \cdot \mathbf{g}\right)$$

$$r_{rms} = \sqrt{\frac{1}{N}\sum_t a_x^2(t) + a_y^2(t) + a_z^2(t)}$$

$$\theta_{i-j} = \arctan\left(\frac{a_{i_{rms}}}{a_{j_{rms}}}\right)$$

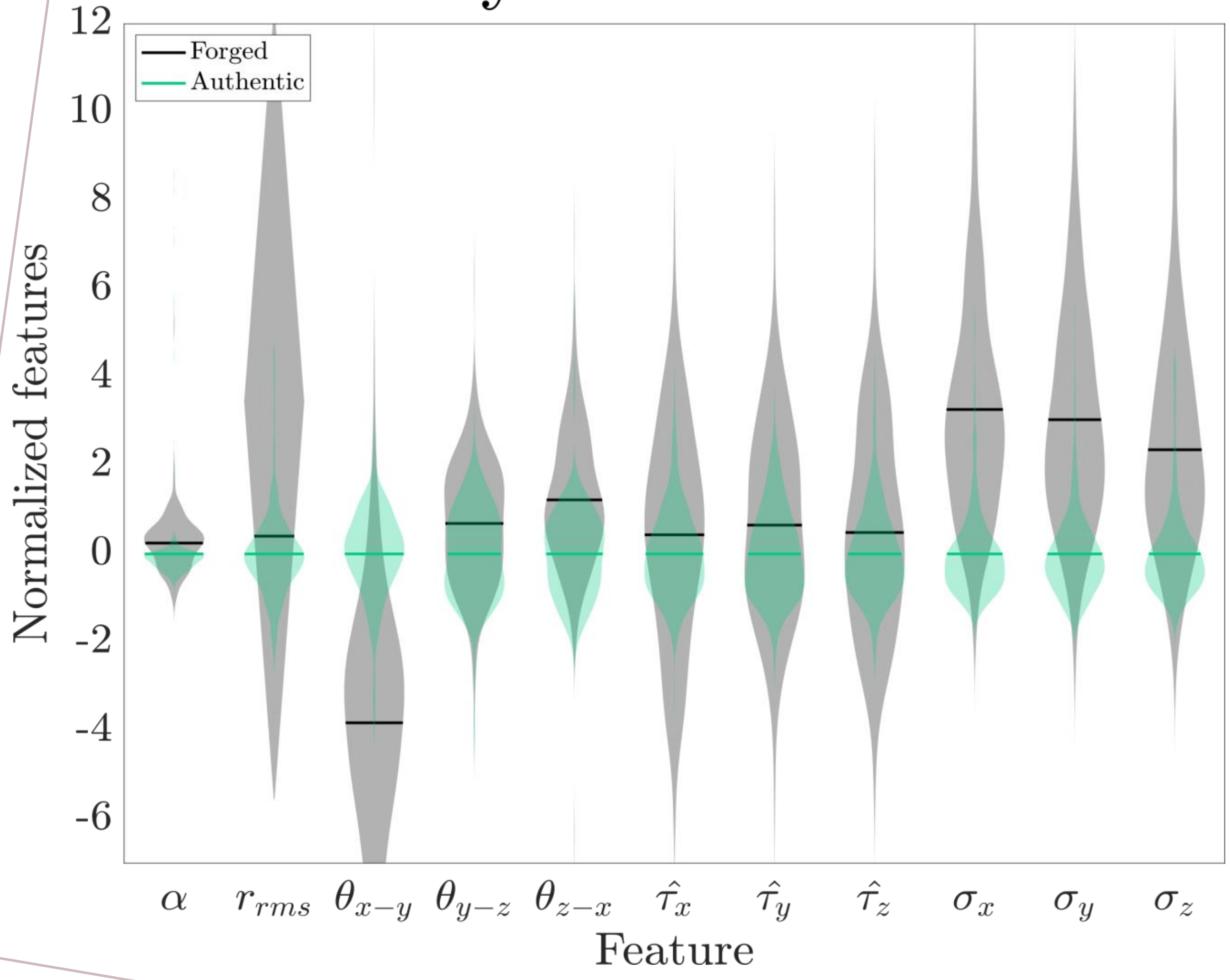
$$\hat{\tau}_i = \frac{1}{N_\tau}\sum_t E_i(t)t$$

$$\sigma_i = \frac{1}{N_\tau}\sum_t E_i(t)t^2 - \hat{\tau}_i$$

$$N_\tau = \sum_t E_i(t)$$

$$E_i(t) = a_i^2(t)$$

Manually Selected Features



α : Angle between gravity and tilt of pen

r_{rms} : Measure of energy put into signature

θ_{i-j} : Ratio of energy distribution on axes i & j

$\hat{\tau}_i$: Metric of temporal distribution of energy (Mean)

σ_i : Metric of temporal distribution of energy (Std)

CLASSIFICATION

A Multilayer Perceptron Neural Network was trained with manually selected features

Input: 22 manually crafted features in **F**

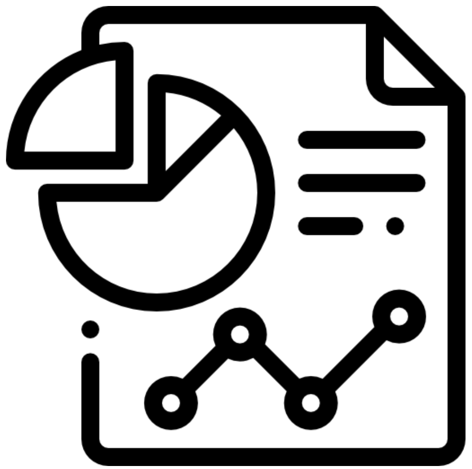
Structure: Three hidden layer with 500, 200, and 50 perceptrons in each layer respectively

Optimization: This model optimized the log-loss function using Limited-memory Broyden– Fletcher–Goldfarb–Shanno (LBFGS)

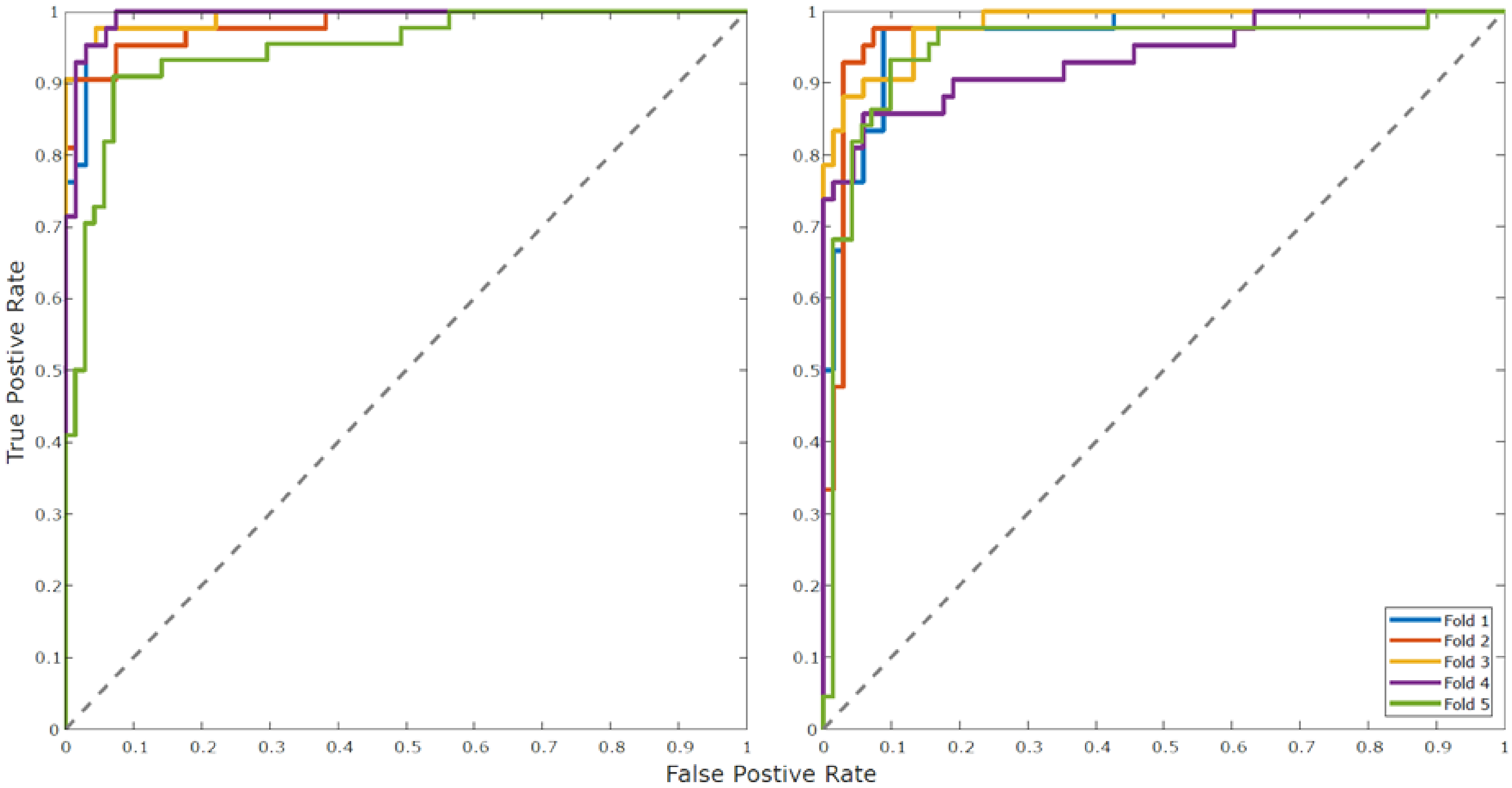
Training: An 80-20 split was heuristically determined

Each dataset was split into 5 distinct folds with uniform distribution of authentic and forged signatures

RESULTS



Receiver Operating Characteristic

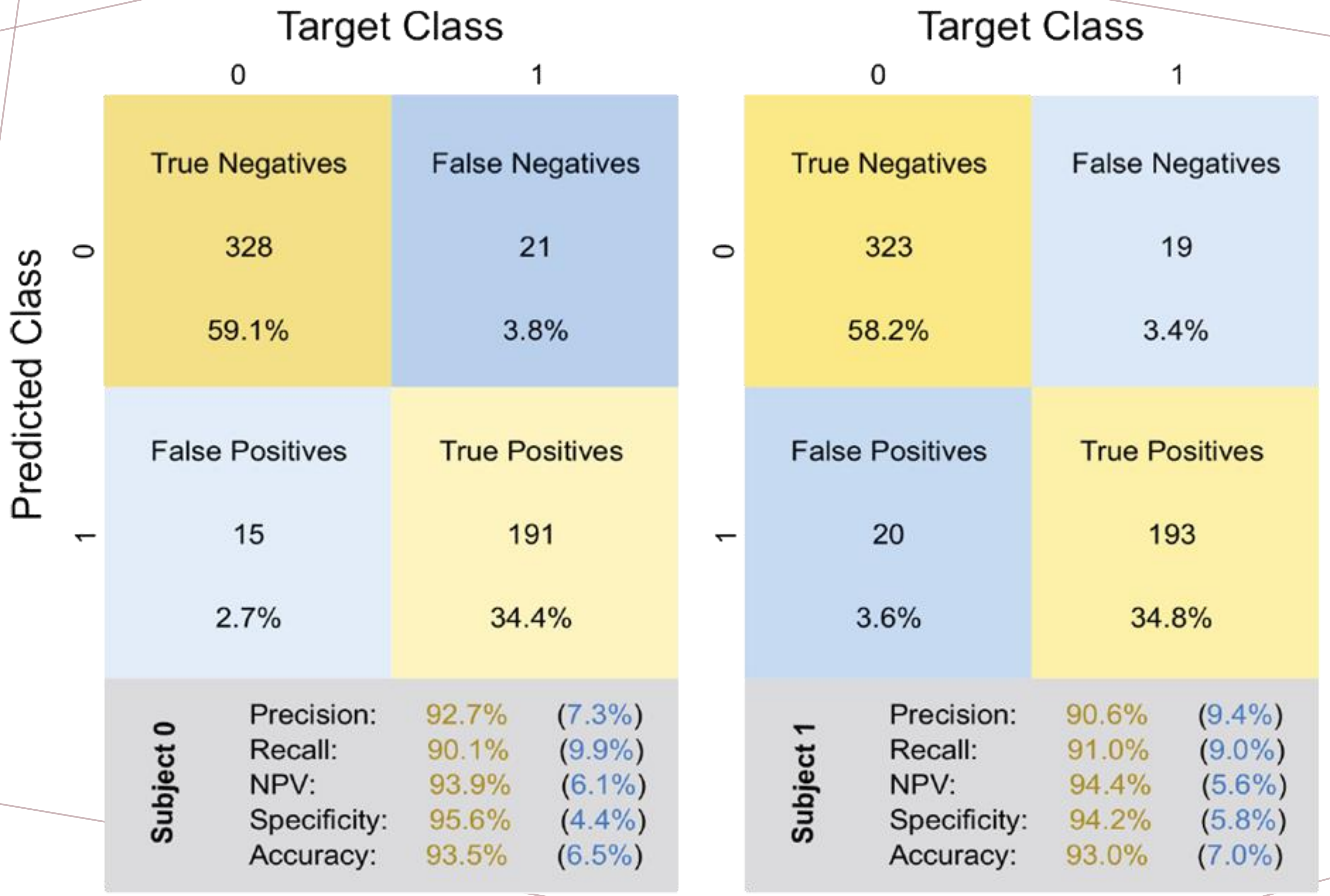


Subject 0

Subject 1

AUC

Fold	Subject 0	Subject 1
1	0.9919	0.9678
2	0.9818	0.9758
3	0.9926	0.9814
4	0.9930	0.9373
5	0.9465	0.9481


Target Class
0
1
Predicted Class
0
1
True Negatives
328
59.1%
False Negatives
21
3.8%
False Positives
15
2.7%
True Positives
191
34.4%
Subject 0
Precision: 92.7% (7.3%)
Recall: 90.1% (9.9%)
NPV: 93.9% (6.1%)
Specificity: 95.6% (4.4%)
Accuracy: 93.5% (6.5%)
Target Class
0
1
0
1
True Negatives
323
58.2%
False Negatives
19
3.4%
False Positives
20
3.6%
True Positives
193
34.8%
Subject 1
Precision: 90.6% (9.4%)
Recall: 91.0% (9.0%)
NPV: 94.4% (5.6%)
Specificity: 94.2% (5.8%)
Accuracy: 93.0% (7.0%)

FUTURE WORKS

Addition of more sensors like pressure sensor and gyrometer

Exploration of other feature extraction and training techniques

Explore on possibility of text transcription with this device

Expanding the study to have more signature as authentication target

THANK YOU

Thank you for your attention. The authors would like to thank the AIM 2023 organizing committee and welcome all questions via email at **kevin.huang@trincoll.edu**

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QUESTIONS

FEATURE DIFFERENCE BETWEEN SQUARES AND CIRCLES